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(71) Applicant *(for all designated States except US)*: **NORTEL NETWORKS LIMITED** [CA/CA]; 2351 Boulevard Alfred-Nobel, St. Laurent, Québec H4S 2A9 (CA).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **TONG, Wen** [CA/CA]; 12 Whitestone Drive, Ottawa, Ontario K2C 4A7 (CA). **VOJCIC, Branmir** [US/US]; 7701 Marbury Road, Bethesda, MD 20817 (US). **PICKHOLTZ, Raymond** [US/US]; 3613 Glenbrook Road, Fairfax, VA 22031 (US). **DAMNJANOVIC, Jelena** [YU/US]; 8540 Costa Verde Boulevard #4335, San Diego, CA 92122 (US).

(74) Agents: **SMITH, Dallas** et al.; Gowling Lafleur Henderson LLP, Suite 2600, 160 Elgin Street, Ottawa, Ontario K1P 1C3 (CA).

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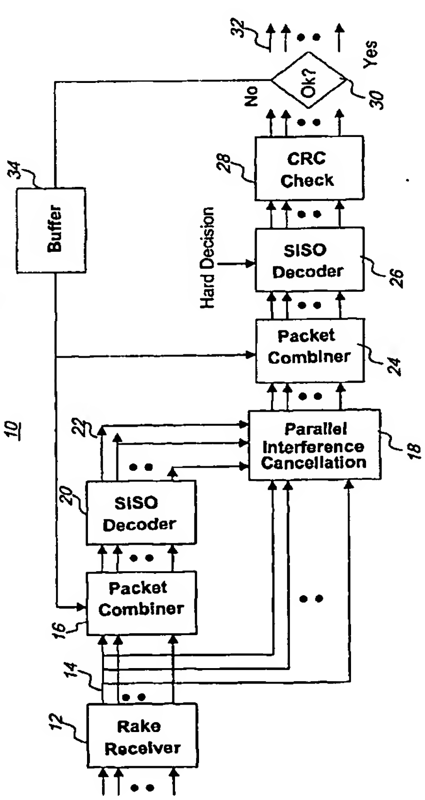
(54) Title: MULTI-USER DETECTOR FOR DIRECT SEQUENCE - CODE DIVISION MULTIPLE ACCESS (DS/CDMA) CHANNELS



(57) Abstract: The present invention combines multi-user detection with packet combining. In multi-user detection, the receiver jointly demodulates user's data by exploiting the structure of multi-user interference, the packet combining is an enhancement of standard automatic repeat request protocol, in which the erroneous packet are not discarded but preserved and combined with retransmitted ones to improve subsequent decisions. One embodiment of the two-stage detector uses a first stage in which the packets are combined and then decoded, in order to improve tentative decisions for interference cancellation. The decoder output is then used in the second stage to cancel the interference, and then the combining is performed once again, before the final decoding. For the two-stage detection we consider two decoding schemes in the first stage. One is the soft input/soft output maximum a posteriori probability decoding of the combined packets, then a soft interference cancellation is performed in the second stage. In the second embodiment, we use the hard decision Viterbi/Turbo decoding, and a hard interference cancellation in the second stage. In the simulation we include power control, quantization, and timing, phase and amplitude estimation. The results indicate that the proposed scheme with packet combining and multi-user detection employed jointly significantly improve performance in the high channel load, increasing the robustness of the system.

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Multi-user Detector for Direct Sequence - Code Division Multiple Access (DS/CDMA) Channels.

Field of the Invention

The present invention relates to a multi-user detector for direct sequence – code division multiple access (DS/CDMA) channels and is particularly concerned with such a detector for use with packet retransmission.

Background of the Invention

The automatic repeat request (ARQ) protocol is common technique used to handle transmission errors incurred by a noisy channel. In most implementations of the ARQ protocol, its sole purpose is error detection. When one or more errors are detected in the received data block, a retransmission request is sent back to the originating transmitter and the erroneous block is discarded. The main drawback of the ARQ schemes is that, especially in case of low signal-to-noise ratio (SNR), the number of retransmissions needed before correct reception may be high, leading to the unacceptably low throughputs. The various modifications of the base-line ARQ protocol, with a goal of enhancing performance, have been proposed in the literature [1], [2], [3]. The major improvement over the standard ARQ protocol can be achieved through the use of the rejected packets by combining them into a single more reliable packet. There are two basic approaches to combine multiple received packets: code combining and diversity combining. The code combining, originally proposed by Chase [4], assumes combining performed at the code-word level, where N packets encoded at rate R create a single packet with code rate R/N. Using rate-compatible punctured convolutional codes and code combing [5], [6] it is possible to get virtually any code rate appropriate to accommodate current channel conditions. The diversity combining involves bit-by-bit combining of multiple packet copies, resulting in a single packet with improved SNR. Although not as powerful as the code combining, the diversity combining is much simpler to implement.

Multiuser detection for direct sequence code division multiple access (DS/CDMA) systems are known [7], [8]. A conventional DS/CDMA receiver considers each user separately, and all interfering users are treated as wide-band noise. In contrast, the approach in multiuser detection is to take into account the structure of the multiuser interference. It has been shown in [9] that the optimum multiuser detector (MUD) offers considerable advantage over the conventional detector, at the expense of the exponential complexity in the number of users. Various MUDs, such as decorrelator [10], MMSE detector [11], and two-stage detector [12], [13], have been proposed that provide performance-complexity trade-offs. While they have polynomial complexity with the number of users and offer substantial performance gains over the conventional detector, they still provide sub-optimal performance.

Summary of the Invention

An object of the present invention is to provide improved multi-user detection (MUD) in direct sequence code division multiple access (DS/CDMA) channels.

Accordingly, the present invention provides an asynchronous DS/CDMA system including a receiver having multi-user detecting and packet combining.

In accordance with an aspect of the present invention there is provided a multi-user detector for wireless communications comprising a first stage having a first packet combiner and a first decoder, and a second stage having a second packet combiner and a second decoder.

In accordance with an aspect of the present invention there is provided a receiver for wireless communications comprising a multi-user detector having a packet combiner and a decoder.

Embodiments of the present invention include a two-stage detector, where in the first stage, in order to improve tentative decisions for the interference cancellation,

the packets are combined and then decoded.

A first embodiment of the present invention includes soft input/soft output Maximum A Posteriori Probability (MAP) decoding of the combined packets. The decoder output is used in the second stage for soft interference cancellation. Then, the combining is performed once again, before the final decoding.

A second embodiment of the present invention includes hard decision Viterbi decoding. The decoder output is used in the second stage for hard interference cancellation. Then, the combining is performed once again, before the final decoding.

Brief Description of the Drawings

The present invention will be further understood from the following detailed description in which:

Fig. 1 illustrates in a block diagram, a multi-user detector in accordance with an embodiment of the present invention;

Fig. 2 illustrates in a functional block diagram an iterative multi-user detector (MUD) with a forward error correction (FEC) soft decoder in accordance with an embodiment of the present invention;

Fig. 3 illustrates in a block diagram an iterative MUD with the FEC hard decoder;

Fig. 4 graphically illustates packet error probability versus number of active users in frequency selective Rayleigh fading channel with power control, finite number of quantization levels and imperfect timing, amplitude and phase estimation;

Fig. 5 graphically illustrates packet error probability versus number of active users in frequency selective Rayleigh fading channel with power control, infinite number of quantization levels and perfect knowledge of timing, amplitude and phase;

Fig. 6 graphically illustrates bit error rates for the embodiment of Fig. 1 compared to a typical rake receiver as a function of number of users per sector;

Fig. 7 graphically illustrates packet error rates for various embodiments of the present invention compared to a typical rake receiver as a function of users per sector;

Fig. 8 illustrates the iterative MUD with soft decoder of Fig. 2, coupled to a single antenna; and

Fig. 9 illustrated the iterative MUD with soft decoder of Fig. 2, coupled to a plurality of antennas.

Detailed Description of the Preferred Embodiment

Referring to Fig. 1 there is illustrated in a block diagram a multi-user detector (MUD) in accordance with an embodiment of the present invention. The MUD 10 includes a rake receiver 12 having a plurality of outputs 14 coupled to a packet combiner 16 and a parallel interference cancellation (PIC) block 18. The output of the packet combiner 16 are applied to a soft input soft output (SISO) decoder 20. The SISO decoder 20 has a plurality of outputs 22 for decoded values. The plurality of outputs 22 are coupled to the PIC block 18. The output of the PIC block 18 is then input into the second packet combiner 24, the output of which is applied as input to a second SISO decoder 26. The output of the second SISO decoder is input to a CRC check 28. A decision block 30 allows output of the received data packet at 32 if no error is found, otherwise the packet is sent to packet buffer 48 and an ARQ is sent to the transmitter, requesting retransmission of the packet.

In operation, the first embodiment of the present invention includes soft input/soft output maximum a posteriori probability (MAP) decoding of the combined packets. The decoder output is used in the second stage for soft interference

cancellation. Then, the combining is performed once again, before the final decoding.

A second embodiment of the present invention includes hard decision Viterbi decoding. The decoder output is used in the second stage for hard interference cancellation. Then, the combining is performed once again, before the final decoding.

After the multiuser detection and packet combining, the packets are decoded and checked for errors using cyclic redundancy check (CRC) code. In the presence of errors, the combiners preserve the combined version of the current erroneous packet and its previous transmissions and negative acknowledgment (NACK) to the originating transmitter is sent. When a packet is error free, the combiners are cleared and positive acknowledgment is sent to the corresponding transmitter.

We assume forward error correction (FEC) with convolutional codes and dual-channel QPSK modulation, i.e. separate BPSK on I- and Q-channel. The I and Q branches are then spread to the chip rate with two different channelization codes. For the asynchronous transmission, the received signal in the mth coded bit interval is modeled as Equation (1):

$$
\begin{aligned}
r(t) &= \sum_{k=1}^{K} A_k b_k(t-\tau_k) S_{I,k}(t-\tau_k)\cdot\cos(\omega_c(t-\tau_k)+\theta_k(t)) \\
&+ \sum_{k=1}^{K} A_k b_k(t-\tau_k) S_{Q,k}(t-\tau_k)\cdot\sin(\omega_c(t-\tau_k)+\theta_k(t)) \\
&+ n(t),
\end{aligned}
$$

where K is the number of users, A_k and $b_k(t)$ represent the received amplitude for the kth user and its received coded bit at time t, respectively. The signature sequences for the I and Q branches are denoted by $S_{i,k}$ (t) and $S_{Q,k}$ (t), respectively. n(t) is additive white Gaussian noise (AWGN) with two-sided power spectral density (psd) No/2, Tk is the delay and ε_k(t) is the phase of the kth user. Each user's signature sequence is normalized over its interval T, Equation (2):

$$\int_0^T S_{I,k}(t)^2\,dt = 1, k\varepsilon\{1,\ldots,\kappa\}$$
$$\int_0^T S_{Q,k}(t)^2\,dt = 1, k\varepsilon\{1,\ldots,\kappa\}$$

After low-pass filtration, assuming that the users' phases are known, and despreading, the signal in the I branch of the kth user in the mth interval becomes, Equation (3):

$$
\begin{aligned}
r^{I}_{k,m} &= \int_{\tau_k+(m-1)T}^{\tau_k+mT} r^{I}_{BB,k}(t) S_{I,k}(t-\tau_k)\,dt \\
&= \frac{1}{2} A_k T b_{k,m} \\
&+ \sum_{\substack{j=1 \\ j\neq k}}^{\kappa} \frac{1}{2} A_j T\left[b_{j,m-1} R^{(1)}_{II,(j,k)}(\tau_j-\tau_k) + b_{j,m} R^{(2)}_{II,(j,k)}(\tau_j-\tau_k)\right] \\
&\cdot \cos(\omega_c(\tau_k-\tau_j)+\varphi_{k,j}) \\
&\sum_{j=1}^{\kappa} \frac{1}{2} A_j T\left[b_{j,m-1} R^{(1)}_{II,(j,k)}(\tau_j-\tau_k) + b_{j,m} R^{(2)}_{II,(j,k)}(\tau_j-\tau_k)\right] \\
&\cdot \sin(\omega_c(\tau_k-\tau_j)+\varphi_{k,j}) \\
&+ \frac{1}{\sqrt{2}} n^{I}_{c,k}
\end{aligned}
$$

where $r^I_{BB,k}$ is the base-band signal of the kth user in the I branch, $b_{k,m}$ is the coded bit of the kth user in the mth interval, and $\varphi_k j(t)=\theta_j(t)-\theta_k(t)$. $R^{(1)}_{II,(j,k)}(\tau_j-\tau_k)\, and\, R^{(2)}_{II,(j,k)}(\tau_j-\tau_k)$ are the partial crosscorrelations between the signature sequences of the jth and the kth user in the I branch, while $R^{(1)}_{QI,(j,k)}(\tau_j-\tau_k)\, and\, R^{(2)}_{QI,(j,k)}(\tau_j-\tau_k)$ are the partial crosscorrelations between the signals of the jth and the Ith user in the Q and I branch, respectively. In a similar way, just by switching I and Q notations, we can obtain $r^{I}_{k,m}$. Combining of the I and Q branch signals yields, Equation (4):

$$
\begin{aligned}
r_{k,m} &= r^{I}_{k,m} + r^{Q}_{k,m} \\
&= A_k T b_{k,m} + MAI + n_{k,m}
\end{aligned}
$$

where MAI denotes over all multiple access interference and $n_{k,m}$ is the Gaussian random variable with two sided psd $N_o/2$.

Conventional detector treats MAI as a wide-band noise. No attempt is made to exploit the structure of MAI. After combining the output of the matched filter in I and Q branches (as given by equation (4)) the signal is combined with the previous unsuccessful transmissions, Equation (5):

$$r_{k,n}^{comb} = \sum_{l=1}^{L_k} A_k^l T b_{k,m} + \sum_{l=1}^{L_k} MAI^1 + \sum_{l=1}^{L_k} n_{k,m} - L_k + 1$$

where L_k is the number of transmissions of the k^{th} user, and superscript I denotes the I^{th} transmission. The combined signal is simply passed to the ordinary soft input hard output Viterbi decoder. The main drawback of this detector is that MAI limited. Its performance will serve as a base line for comparison with other detectors. Although in the simulations we use an asynchronous transmission, let us now, for the clarity of explanation, consider a synchronous transmission.

Referring to Fig. 2 there is illustrated in a functional block diagram an iterative multi-user detector (MUD) with a forward error correction (FEC) soft decoder in accordance with an embodiment of the present invention. The iterative MUD decoder of Fig. 2 includes the rake receiver 12, the packet combiner 16, the parallel interference canceller 16 and the SISO decoder 20 of Fig. 1 shown in further detail. A received rake signal is passed through a low pass filter (LPF) 40 before being applied to the rake receiver 12. Detail of the decoder shown for one user (a user 1) which should be understood to have a plurality of similar configurations for decoding with regard to the remaining 2-K users. The rake receiver12 includes a plurality K of M correlators 42 (M fingers for each K users) to provide the initial decoding of the received signal. The output of the correlators are combined in a MRC combiner 16 before input to decoder 20. The decoder 20 includes the de-interleaver 44, an SISO decoder 46, an encoder 48, and the interleaver 50 for each user path 52a to 52k.

Decoder for a particular user e.g., users 1 in Fig. 2 includes a parallel interference cancellation block 18 that include user path 52 b and 52 k and signal regenerators 54 b to 54 k. These regenerate the other signals for subtraction from the rake received signal for user 1 that the adder 56.

The basic idea of the soft output decoding is to obtain soft values, or reliability values of the coded symbols. The initial values for the coded symbols' reliability are all zeros, and hence the first step in this scheme is the computation of the log-likelihood ratio of the crossover probabilities (for a binary symmetric channel), which is called the reliability value of the channel. For a single user transmission case $L_c=4a\cdot E/N_0$[14]. For the multiuser scenario considered here, we treat MAI as a wide-band noise, and the soft channel output is given by Equation (6):

$$L_c = 2a\frac{E}{\frac{N_0}{2}+\overline{MAI^2}}$$

where E is the signal energy per coded symbol, a is the fading amplitude and $\overline{MAI^2}$ is the second moment of MAI per coded symbol. The channel reliability values are combined in the first stage packet combiner, and its output is led to the soft input-soft output decoder. The second step in the proposed scheme consists of FEC soft-decision decoding using MAP [14] decision rule. In order to perform soft-decision interference cancellation it is necessary to have reliability of coded symbols. Classical MAP produces reliability of information bits, but it can be easily modified to produce reliability of coded symbols. Denote with $p_{j,m}=\frac{e(L_{j,m})}{1+e(L_{j,m})}$ the probability that the m^{th} coded symbol of user j is correctly decoded, where $L_{j,m}$ is the coded symbol reliability after FEC decoding. The mean value for the m^{th} coded symbol of user j is given by $2p_{j,m}-1$. The signal of the k^{th} user in the m^{th} bit interval at the second stage, after the second combining, and before the final FEC decoding is Equation (7):

$$
\begin{aligned}
r_{k,m}^{2st,comb} &= \sum_{l=1}^{L_k} \sqrt{E_k^1}\, b_{k,m} \\
&+ \sum_{l=1}^{L_k} \sum_{\substack{j=1 \\ j\neq k}}^{K} \frac{1}{2}\Big\{\Big(\sqrt{E_j^1}\, b_{j,m} - L_k + 1 - \sqrt{\hat{E}_j^1}\, \hat{b}_{j,m} - L_k + 1(2\rho_{j,m} - L_k + 1 - 1)\Big) \\
&\cdot \Big[\big(R_{II,(j,k)}^1 + R_{QQ,(j,k)}^1\big)\cos \ell_{k,j}^1 + (R_{QI,(j,k)}^1)\sin \ell_{k,j}^1\Big]\Big\} \\
&+ \sum_{l=1}^{L_k} n_{k,m} - L_k + 1
\end{aligned}
$$

This signal has improved SNIR relative to the original signal, that is, $\overline{MAI^2}$ is significantly reduced.

Referring to Fig. 3 there is illustrated in a block diagram and iterative MUD with the FEC hard decoder. The components of the decoder in Fig. 3 are similar to those of Fig. 2 except for decoder 46' that is a hard of Viterbi/Turbo decoder.

Input to the hard output Viterbi/Turbo decoder is given by the eq. (5). Hard output after decoding is then encoded and used for interference cancellation in the second stage. After the interference cancellation is performed, signal is combined once again, and before it is sent for the final FEC decoding, it can be represented as Equation (8):

$$
\begin{aligned}
r_{k,m}^{2st,comb} &= \sum_{l=1}^{L_k} \sqrt{E_k^1}\, b_{k,m} \\
&+ \sum_{l=1}^{L_k} \sum_{j=1}^{K} \frac{1}{2}\Big\{\Big(\sqrt{E_j^1}\, b_{j,m} - L_k + 1 - \sqrt{\hat{E}_j^1}\, \hat{b}_{j,m} - L_k + 1\Big) \\
&\cdot \Big[\big(R_{II,(j,k)}^1 + R_{QQ,(j,k)}^1\big)\cos \varphi_{k,j}^l + (R_{QI,(j,k)}^1)\sin \varphi_{k,j}^1\Big]\Big\} \\
&+ \sum_{l=1}^{L_k} n_{k,m} - L_k + 1
\end{aligned}
$$

where $E_j^1 = (A_j^1 T)^2$ and $\hat{E}_j^1$ *and* $\hat{b}_{j,m} - L_n + 1$ are the estimated values of E_j^1 *and* $b_{j,m} - L_k + 1$ and $b_{j,m}\_L_k+1$, respectively, obtained for the Ith transmission at the jth output of the first stage detector. The motivation for employing the interference

cancellation after decoding (and then re-encoding) is that it can provide better tentative symbol estimates, $\hat{b}_{j,m}$, in the first stage and also enable better estimation of the received amplitudes and phases, needed for feedback interference cancellation.

Although in the simulations we use an asynchronous transmission, let us now, for the clarity of explanation, consider a synchronous transmission.

The numerical results that we present are based on Monte Carlo simulations. We consider conventional detector, two-stage detector with hard output Viterbi/Turbo decoding in the first stage and hard interference cancellation, and two-stage detector with soft output MAP decoding in the first stage and soft interference cancellation, all with and without packet combining. The simulation model assumes chip synchronous and bit asynchronous transmission, packet size of 1280 bits, FEC with rate 1/2, constraint length 9 convolutional code, and CRC code C5 from [15]. The considered data bit rate is 128 kbps and the spreading factor per information bit is 8. Cannel is Rayleigh fading with Doppler frequency of 83.3 Hz and two equal power paths. All paths are tracked in a RAKE structured receiver with the maximum ratio combining. We employ the coherent detection of BPSK modulated signals with pilot aided detection. In the simulation we include block interleaving, imperfect power control, finite number of quantization levels, imperfect timing and imperfect amplitude and phase estimation.

The fast power control is employed with 1600 updates per second. It compensates for medium to fast fading by measuring the average pilot signal level at the output of the matched filter, and performing appropriate adjustments. The adjustments are implemented as follows: the transmission powers of the users that are 1 [dB] or more under the nominal power level is increased by 1 [dB], while the transmission powers of the users which are 1 [dB] or more over the nominal power level is decreased by 1 [dB]. The nominal signal to noise ratio was chosen to be $E_b/N_o = 7$ [dB].

The 16 level uniform quantization is performed at the matched filters outputs. The quantization step, with respect to the normalized unit energy signal is 0.25. This value is chosen since the statistical analysis of the matched filter outputs showed that the normalized signal values are concentrated in the interval from -2 to +2.

Imperfect timing is included in the simulation model by introducing 1/8 chip timing resolution. When despreading was performed, instead of multiplying the received signal of the desired user by the corresponding spreading sequence with perfectly matched timing, it was multiplied by the shifted version of the same sequence. The shift was chosen to be a random number, taking the values 0, 1/64, 1/48, 1/32, and 1/16 of the chip interval with equal probabilities.

In order to obtain better amplitude estimates in the Rayleigh fading channel, the single amplitude estimates, obtained from the matched filter outputs after the interference cancellation, were averaged over 150 consecutive realizations.

In Fig. 4 we present throughput as a function of number of active users. The results are obtained under realistic assumptions that include all previously mentioned imperfections: imperfect power control, imperfect amplitude, phase and timing estimation, block interleaving, and finite number of quantization levels. It can be seen that combining increases robustness of all considered detectors. The best performance is achieved with the scheme involving packet combining and two-stage detector with soft interference cancellation. At the throughput of 0.5, soft interference cancellation with packet combining offers a gain of about 60% over soft interference cancellation, 50% and 130% over conventional detector with and without packet combining, respectively, and 40% and 75% over hard interference cancellation, with and without packet combining, respectively.

In order to investigate the influence of the implementation imperfections, we simulated the system assuming the perfect amplitude, phase and timing knowledge and infinite level quantization at the receiver side. The results, shown in Fig. 5, indicate that improvements, due to employment of packet combining in conjunction

with MUD, are even greater when imperfections are not present. Again, two-stage detector with soft interference cancellation and packet combining exhibits the best performance. Note that now two-stage detector with hard interference cancellation and packet combining is better for the whole range of considered parameters than the conventional detector with packet combining, while it was not the case when imperfections are included. The reason for such behavior is in the fact that when the number of active users increases in the system with imperfections, and therefore MAI increases, it causes the decrease in quality of parameter estimation, and high error rate of the tentative decisions in the first stage. Thus, these two effects lead to the inaccurate or totally erroneous interference cancellation, resulting in the MAI increase.

Referring to Fig. 6 there is graphically illustrated bit error rates for the embodiment of Fig. 1 compared to a typical rake receiver as a function of number of users per sector.

Referring to Fig. 7 there is graphically illustrated packet error rates for various embodiments of the present invention compared to a typical rake receiver as a function of users per sector. The embodiments can provide more users capacity in the sector.

Referring to Fig. 8 there is illustrated the iterative MUD with soft decoder of Fig. 2, coupled to a single antenna. The single antenna 60 is coupled to a low pass filter 40.

Referring to Fig. 9 there is illustrated the iterative MUD with soft decoder of Fig. 2, coupled to a plurality of antennas. The configuration of Fig. 9 includes a plurality of antennas 60 and 64 each coupled to a corresponding plurality of low pass filters 40 and 40' and a plurality of rake receivers 42 and 42'. The output of the rake receivers are applied to a maximum ratio combined 16 for each user when - 1 to K. While Fig. 9 shows a plurality of two antennas, the principle is easily extended to greater plurality of antennas.

In accordance with embodiments of the present invention we provided, simulated and analyzed the receiver employing jointly packet combining and multiuser detection. Frequency selective Rayleigh fading channel, FEC and asynchronous transmission, with and without system implementation imperfections, have been considered. We have provided two embodiments: two-stage detection of combined packets with soft and hard interference cancellation. The first embodiment involves soft input/soft output MAP decoding of the combined packets in the first stage, and the soft interference cancellation in the second stage. In the second embodiment we use the hard decision Viterbi/Turbo decoding to decode combined packets in the first stage, and hard interference cancellation in the second stage. Simulations have shown that the present embodiments with MUD and packet combining can achieve considerable performance gains compared to their counterparts without packet combining, as well as conventional detector with and without packet combining. As the number of active users increases, the throughput of the detectors without packet combining drops rapidly to zero, while in conjunction with packet combining they achieve significant throughput, and therefore considerably improve system robustness. The best performance is achieved by the two-stage detector with soft interference cancellation and packet combining. The advantage of multiuser detection over the conventional detection is even more pronounced when they are employed with packet combining, and when system imperfections are not present.

Additional definitions of embodiments of the invention

1. An apparatus for detection of performance in multiuser communications, the apparatus comprising a multiuser detection device and a packet combining device which is coupled with the multiuser detection device.

2. The apparatus of definition 1, wherein the multiuser detection device comprises a receiving device for receiving users' data.

3. The apparatus of definition 2, wherein the receiving device comprises device for demodulating jointly users' data by exploiting the structure of multi-user interference.

4. The apparatus of definition 1, wherein the packet combining device comprises an enhancement device for enhancing standard automatic repeat request protocol.

5. The apparatus of definition 4, wherein the enhancement device comprises:

a device for preserving erroneous packets without discarding; and

a device for combining the preserved packets with retransmitted packets, thereby improving new decisions.

6. The apparatus of definition 1, further comprising a two-stage detection device.

7. The apparatus of definition 6, wherein the detection device comprises first and second stage detectors.

8. The apparatus of definition 7, wherein the first stage detector comprises a decision device for making a tentative decision on interference cancellation.

9. The apparatus of definition 8, wherein the decision device comprises a packet combining device and a decoding device.

10. The apparatus of definition 9, wherein the second stage detector comprises a device for receiving decoded output provided by the decoding device of the first stage detector, so as to cancel the interference.

11. The apparatus of definition 10, wherein the second stage detector further comprises a device for combining the received decoded outputs before final decoding.

12. The apparatus of definition 7 used for asynchronous transmission and coherent detection in Rayleigh fading channel, with forward error correction.

13. The apparatus of definition 12, wherein the first stage decoder comprises a device for performing soft input/soft output Maximum A Posteriori Probability decoding.

14. The apparatus of definition 12, wherein the second stage detector comprises a device for performing soft interference cancellation.

15. The apparatus of definition 14, wherein the decoder comprises a device for performing the hard decision Viterbi/Turbo decoding.

16. The apparatus of definition 15, wherein the second stage detector comprises a device for performing hard interference cancellation.

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What is claimed is:

1. A multi-user detector for wireless communications comprising:

   a first stage having a first packet combiner and a first decoder; and

   a second stage having a second packet combiner and a second decoder.

2. A multi-user detector as claimed in claim 1 wherein the first stage includes a rake receiver whose output is coupled to the first packet combiner.

3. A multi-user detector as claimed in claim 1 wherein the first stage includes an interference canceller whose output is coupled to the second packet combiner.

4. A multi-user detector as claimed in claim 1 wherein the first decoder is a hard decoder.

5. A multi-user detector as claimed in claim 4 wherein the first decoder is a Viterbi/ Turbo decoder.

6. A multi-user detector as claimed in claim 1 wherein the first decoder is a hard decoder.

7. A multi-user detector as claimed in claim 6 wherein the first decoder is a Viterbi/ Turbo decoder.

8. A multi-user detector as claimed in claim 3 wherein the first decoder is a soft decoder.

9. A multi-user detector as claimed in claim 8 wherein the first decoder is a maximum a posteriori probability decoder.

10. A multi-user detector as claimed in claim 9 wherein the first decoder includes outputs for probability values that are coupled to the interference canceller.

11. A receiver for wireless communications comprising:

a multi-user detector having a packet combiner and a decoder.

12. A receiver as claimed in claim 11 wherein the multi-user detector includes a rake receiver whose output is coupled to the packet combiner.

13. A multi-user detector as claimed in claim 11 wherein the multi-user detector includes an interference canceller.

14. A multi-user detector as claimed in claim 11 wherein the decoder is a hard decoder.

15. A multi-user detector as claimed in claim 14 wherein the first decoder is a Viterbi/ Turbo decoder.

16. A multi-user detector as claimed in claim 11 wherein the decoder is a soft decoder

17. A method for detecting performance in multi-user communications, the method comprising the steps of multi-user detection and packet combining

18. The method of Claim 17, wherein the multi-user detection step comprises the step of receiving users' data.

19. The method of Claim 18, wherein the receiving step comprises the step of demodulating jointly users' data by exploiting the structure of multiuser interference.

20. The method of Claim 17, wherein the packet combining step comprises the step of enhancing standard automatic repeat request protocol.

21. The method of Claim 20, wherein the enhancement step comprises the steps of:

preserving erroneous packets without discarding; and

combining the preserved packets with retransmitted packets, thereby improving new decisions.

22. The method of Claim 17, further comprising the step of performing two stage detection.

23. The method of Claim 22, wherein the detection step comprising the steps of first and second stage detections.

24. The method of Claim 23, wherein the first stage detection step comprises the step of making a tentative decision on interference cancellation.

25. The method of Claim 24, wherein the decision step comprises the step of packet combining and decoding.

26. The method of Claim 25, wherein the second stage detection means comprises the step of receiving decoded output provided by the decoding step of the first stage detection step, so as to cancel the interference.

27. The method of Claim 26, wherein the second stage detection step further comprises the step of combining the received decoded outputs before final decoding.

28. The method of Claim 23 used for asynchronous transmission and coherent detection in Rayleigh fading channel, with forward error correction.

29. The method of Claim 28, wherein the first stage detection step comprises the step of performing soft input/soft output Maximum A Posteriori Probability decoding.

30. The method of Claim 28, wherein the second stage decoding step comprises the step of performing soft interference cancellation.

31. The method of Claim 27, wherein the decoding step comprises the step of performing the hard decision Viterbi/Turbo decoding.

32. The method of Claim 31, wherein the second stage detection step comprises the step of performing hard interference cancellation.

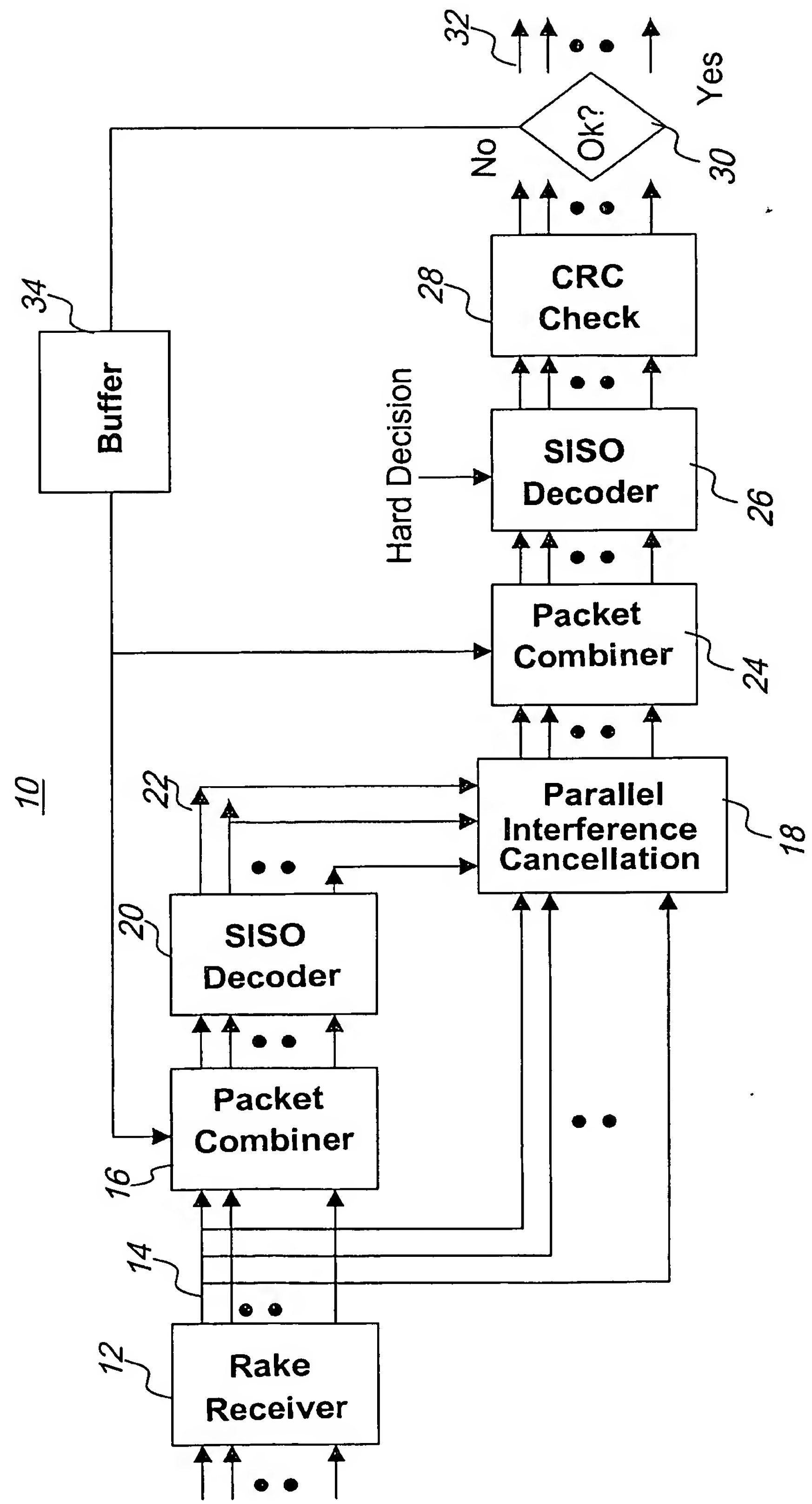
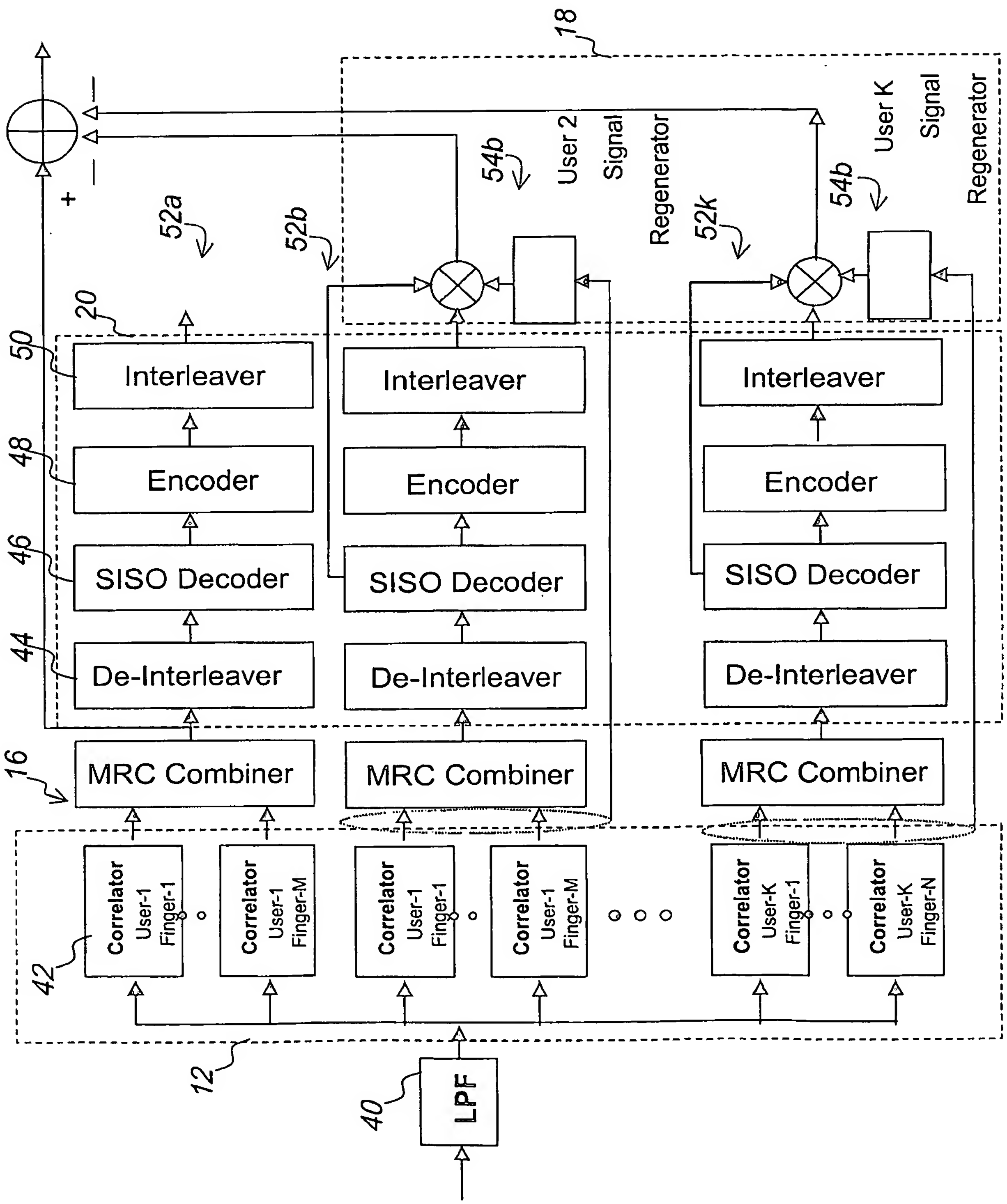

10
Rake Receiver
12
14
Packet Combiner
16
SISO Decoder
20
22
Parallel Interference Cancellation
18
Packet Combiner
24
SISO Decoder
26
Hard Decision
CRC Check
28
Ok?
30
No
Yes
32
Buffer
34

Fig. 1

Fig. 2


18
User 2
Signal
Regenerator
User K
Signal
Regenerator
54b
54b
52a
52b
52k
20
50
48
46
44
16
42
12
40
+
Interleaver
Encoder
SISO Decoder
De-Interleaver
MRC Combiner
Correlator
User-1
Finger-1
Correlator
User-1
Finger-M
Correlator
User-K
Finger-1
Correlator
User-K
Finger-N
LPF

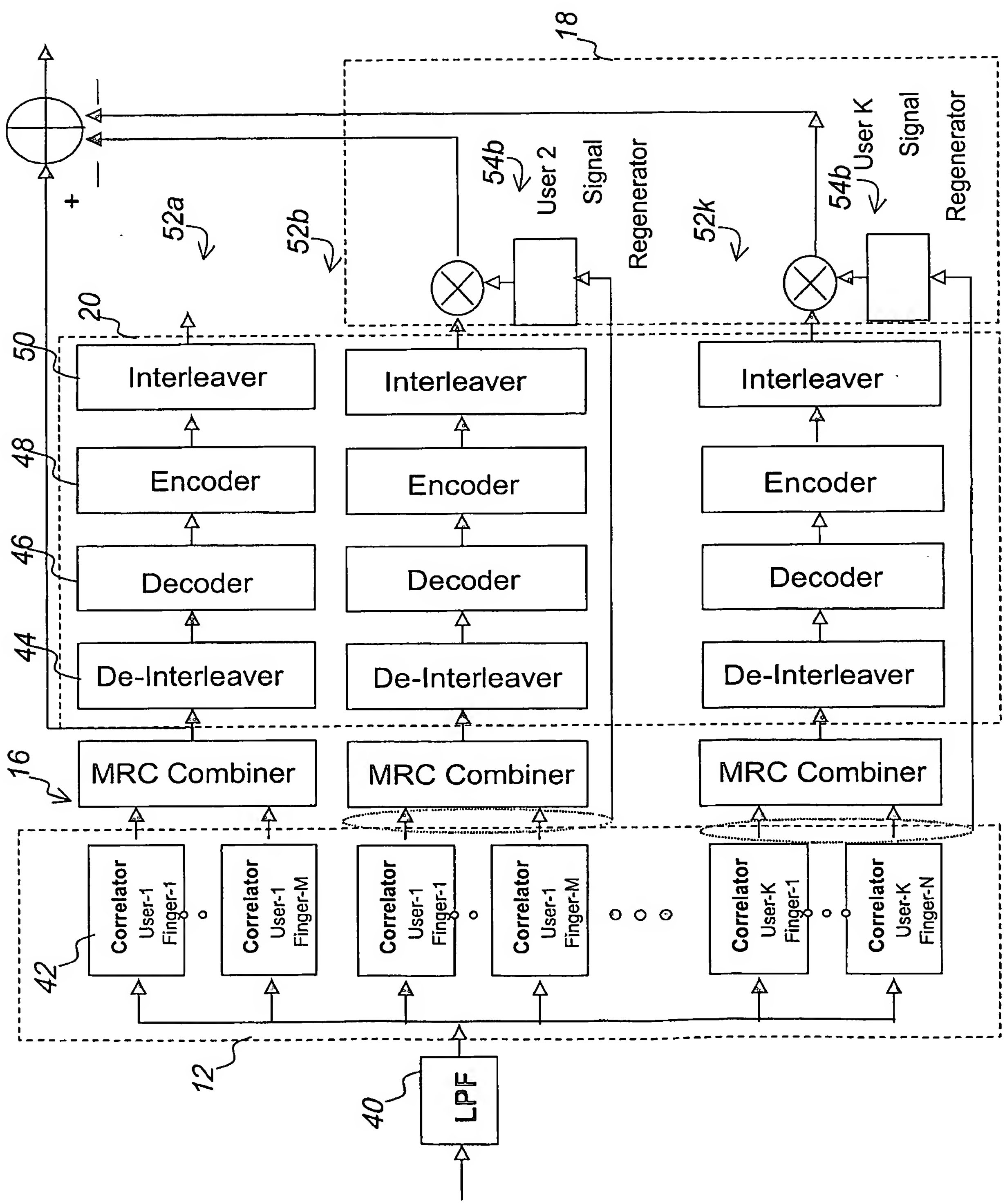
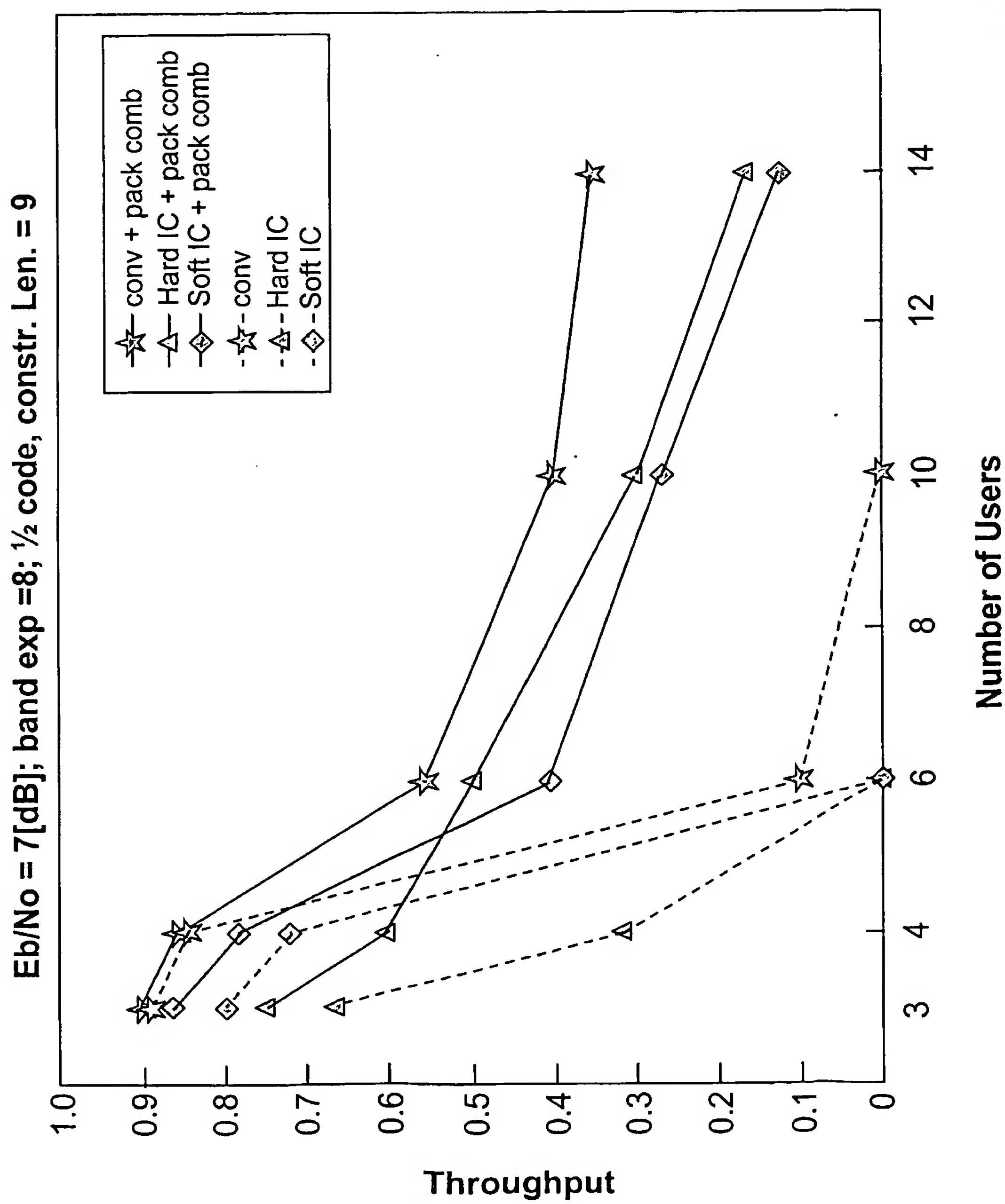

18
+
52a
52b
54b
User 2
Signal
Regenerator
52k
54b
User K
Signal
Regenerator
20
50
Interleaver
Interleaver
Interleaver
48
Encoder
Encoder
Encoder
46
Decoder
Decoder
Decoder
44
De-Interleaver
De-Interleaver
De-Interleaver
16
MRC Combiner
MRC Combiner
MRC Combiner
Correlator User-1 Finger-1
Correlator User-1 Finger-M
Correlator User-1 Finger-1
Correlator User-1 Finger-M
Correlator User-K Finger-1
Correlator User-K Finger-N
42
12
40
LPF

Fig. 3



Eb/No = 7[dB]; band exp =8; ½ code, constr. Len. = 9
conv + pack comb
Hard IC + pack comb
Soft IC + pack comb
conv
Hard IC
Soft IC
Throughput
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Number of Users
3
4
6
8
10
12
14

Fig. 4

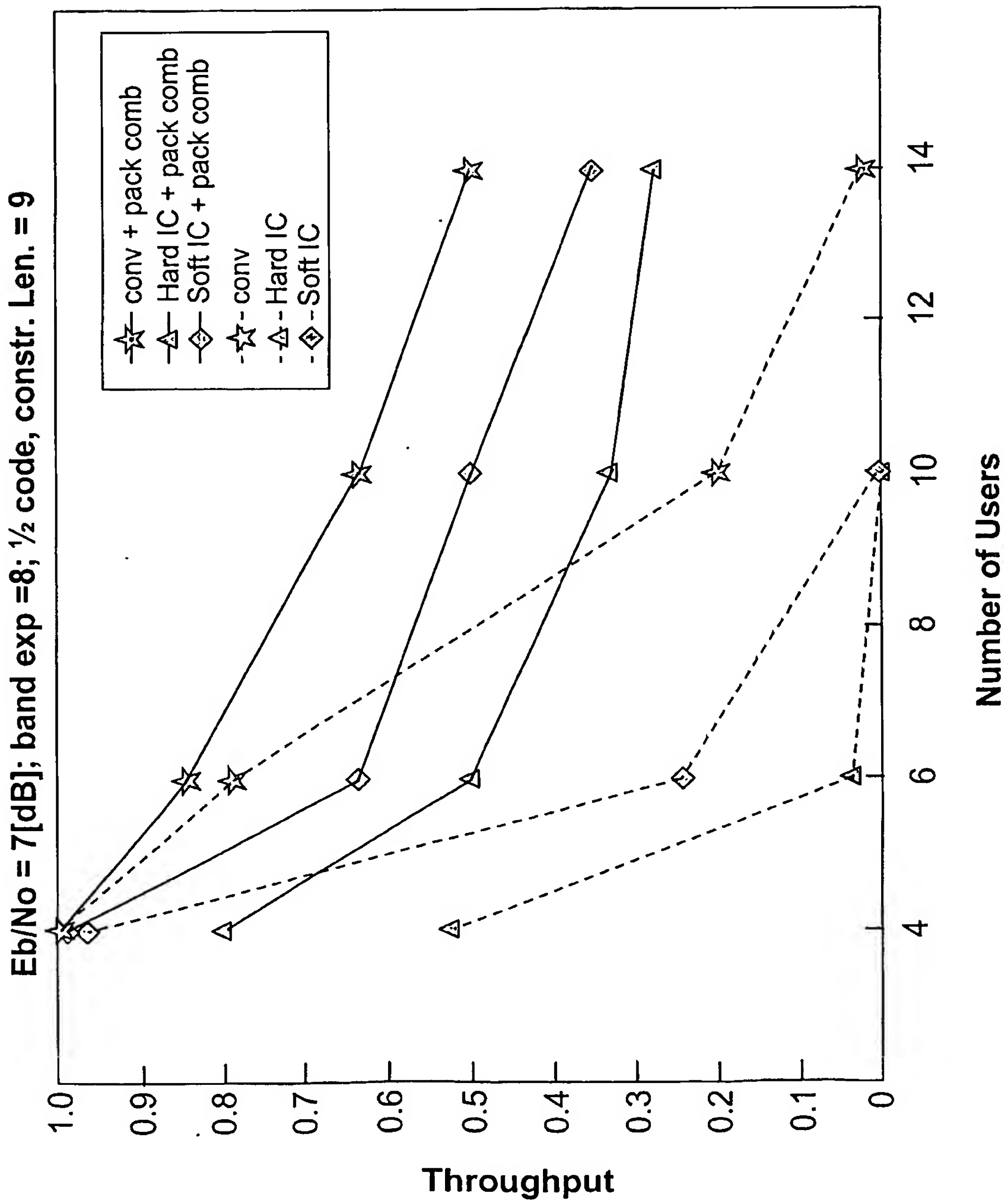

Eb/No = 7[dB]; band exp =8; ½ code, constr. Len. = 9
conv + pack comb
Hard IC + pack comb
Soft IC + pack comb
conv
Hard IC
Soft IC
Throughput
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
4
6
8
10
12
14
Number of Users

Fig. 5

Fig. 6

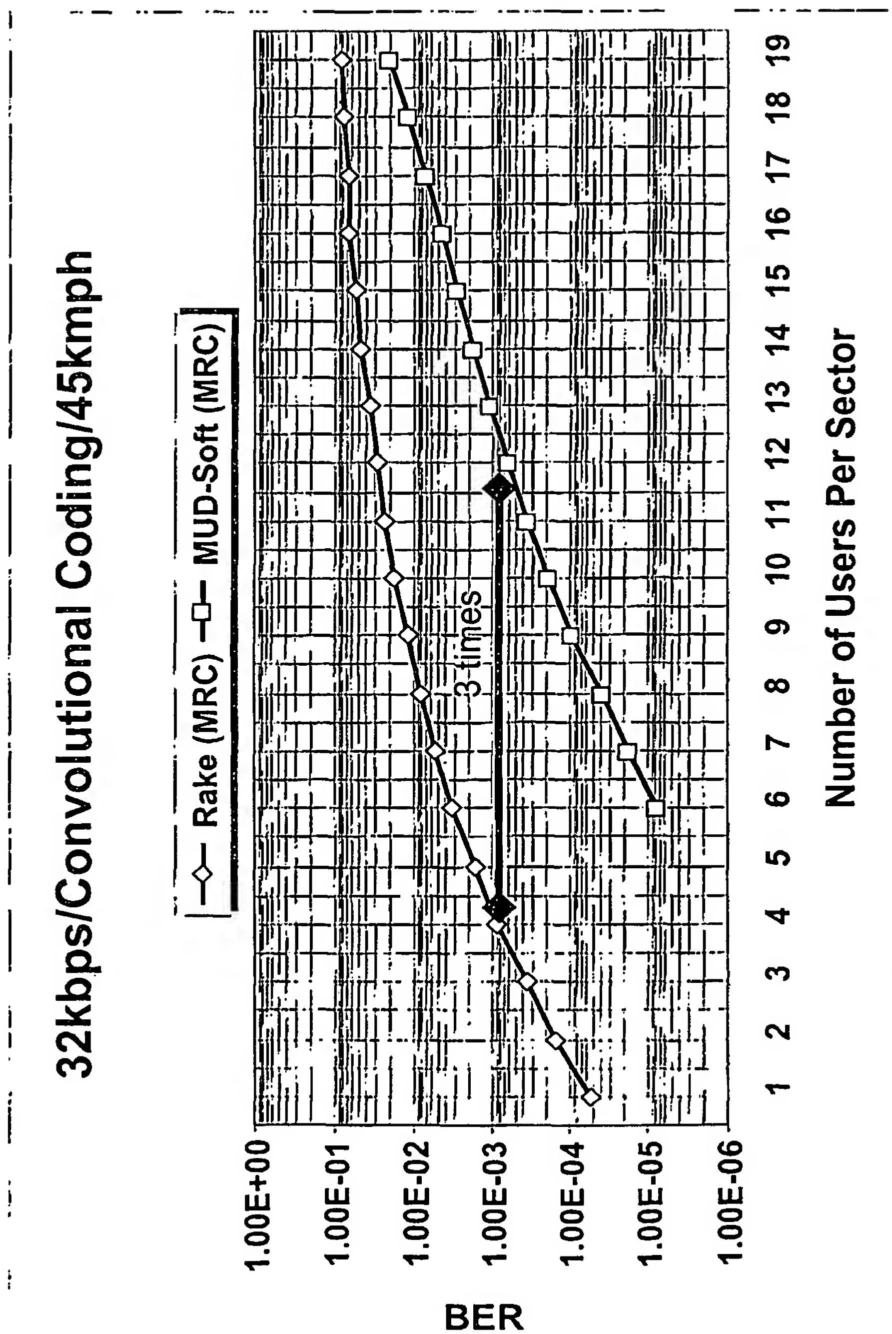

32kbps/Convolutional Coding/45kmph
Rake (MRC)
MUD-Soft (MRC)
3 times
BER
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Number of Users Per Sector

Fig. 7

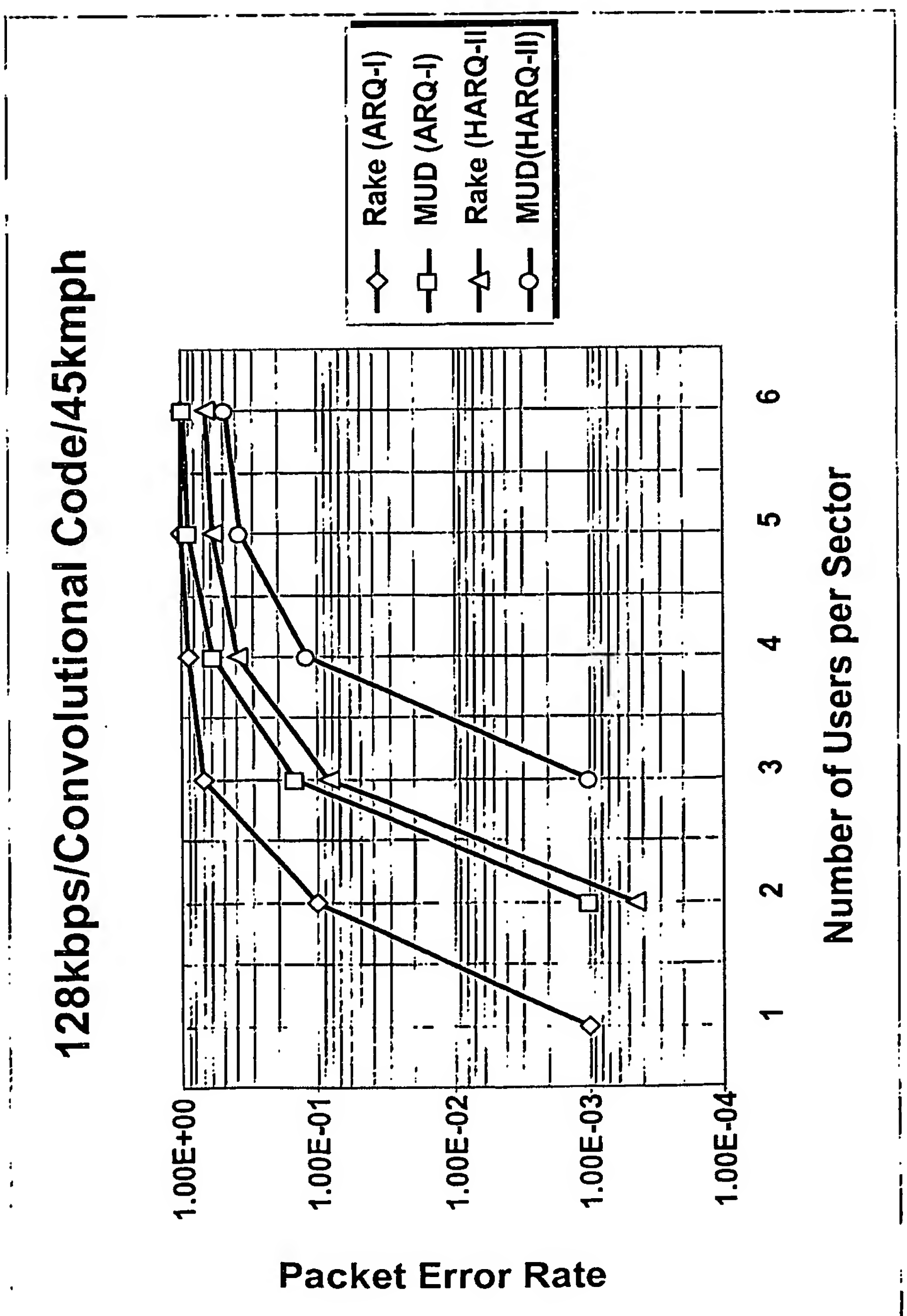

128kbps/Convolutional Code/45kmph
Rake (ARQ-I)
MUD (ARQ-I)
Rake (HARQ-II)
MUD(HARQ-II)
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1
2
3
4
5
6
Number of Users per Sector
Packet Error Rate

Fig. 8

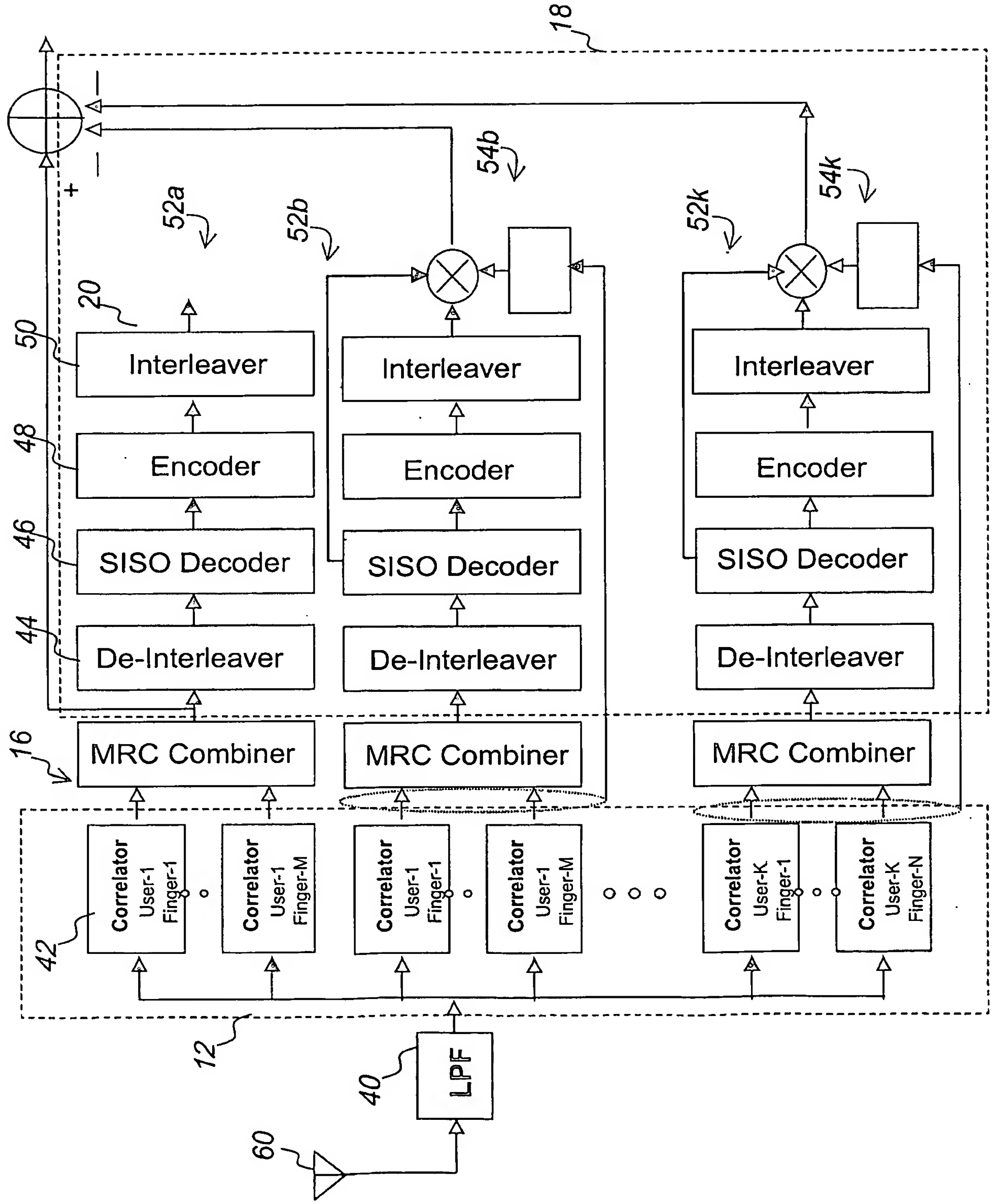
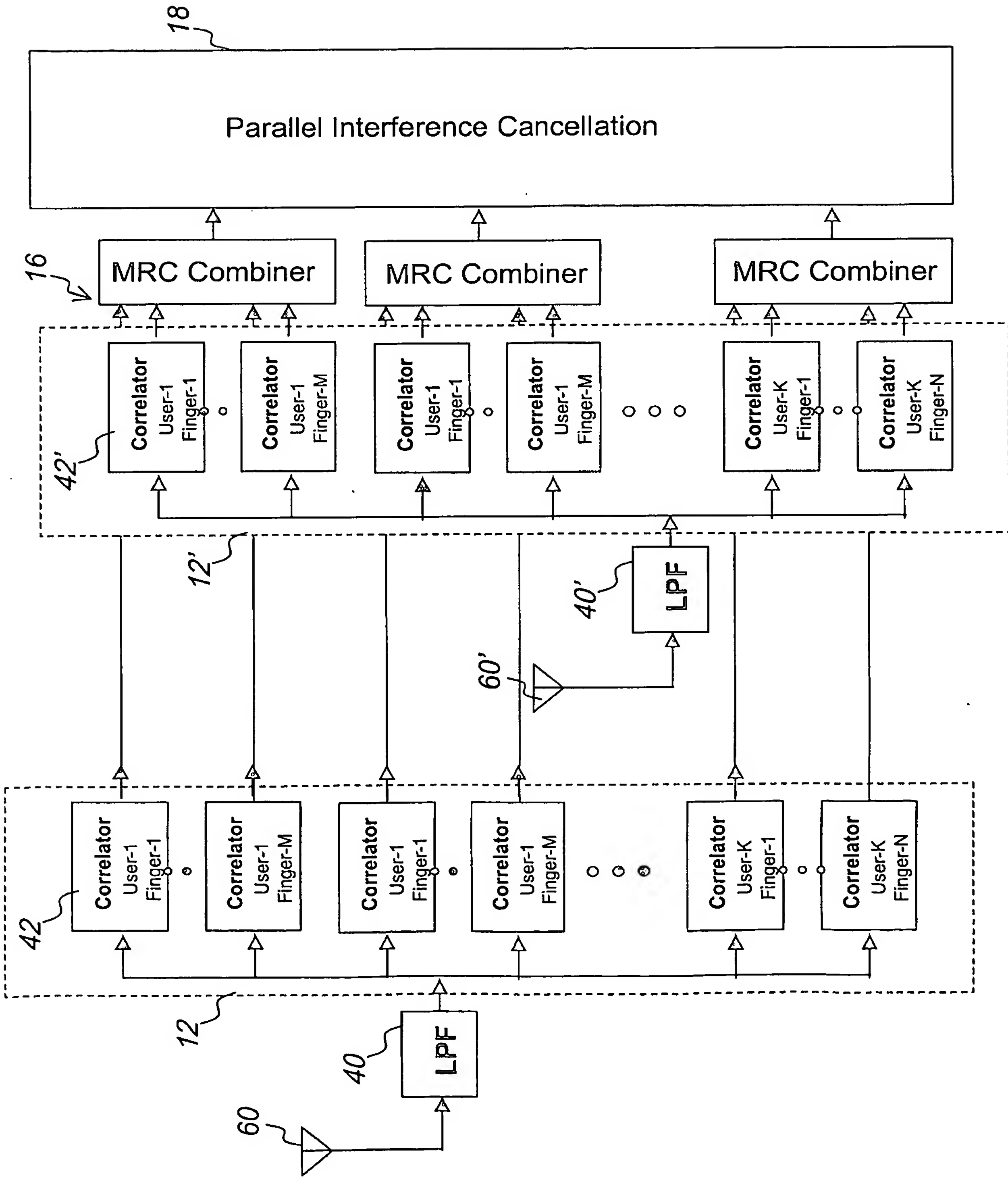

18
54b
54k
52a
52b
52k
20
50
48
46
44
16
42
12
40
60
+
Interleaver
Encoder
SISO Decoder
De-Interleaver
MRC Combiner
Correlator User-1 Finger-1
Correlator User-1 Finger-M
Correlator User-K Finger-1
Correlator User-K Finger-N
LPF

Fig. 9


18
Parallel Interference Cancellation
16
MRC Combiner
MRC Combiner
MRC Combiner
Correlator User-1 Finger-1
Correlator User-1 Finger-M
Correlator User-1 Finger-1
Correlator User-1 Finger-M
Correlator User-K Finger-1
Correlator User-K Finger-N
42'
12'
LPF
40'
60'
Correlator User-1 Finger-1
Correlator User-1 Finger-M
Correlator User-1 Finger-1
Correlator User-1 Finger-M
Correlator User-K Finger-1
Correlator User-K Finger-N
42
12
LPF
40
60